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(54) **INTRAOPERATIVE STEREO IMAGING SYSTEM**

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**H05G 1/02** (2006.01)

(52) **U.S. Cl.** ..... **378/42; 378/41; 378/189; 378/190; 378/197; 600/429**

(58) **Field of Classification Search** ..... **378/5, 378/9, 41, 42, 92, 98.9, 190, 196-198, 205, 378/11, 25, 26, 181, 206, 19; 600/407, 424, 600/425, 429**  
See application file for complete search history.

(56) **References Cited**  
U.S. PATENT DOCUMENTS

4,341,220 A 7/1982 Perry

4,349,740 A \* 9/1982 Grassmann et al. .... 378/25  
4,737,972 A \* 4/1988 Schoolman ..... 378/41  
4,791,934 A \* 12/1988 Brunnett ..... 600/429  
5,078,140 A \* 1/1992 Kwoh ..... 600/417  
5,099,846 A 3/1992 Hardy  
5,446,548 A \* 8/1995 Gerig et al. .... 356/620  
5,665,095 A 9/1997 Jacobson

(Continued)

**FOREIGN PATENT DOCUMENTS**

WO WO 94/10908 5/1994  
WO WO 00/64367 11/2000  
WO WO 02/065931 A1 8/2002  
WO WO 03/009768 A1 2/2003

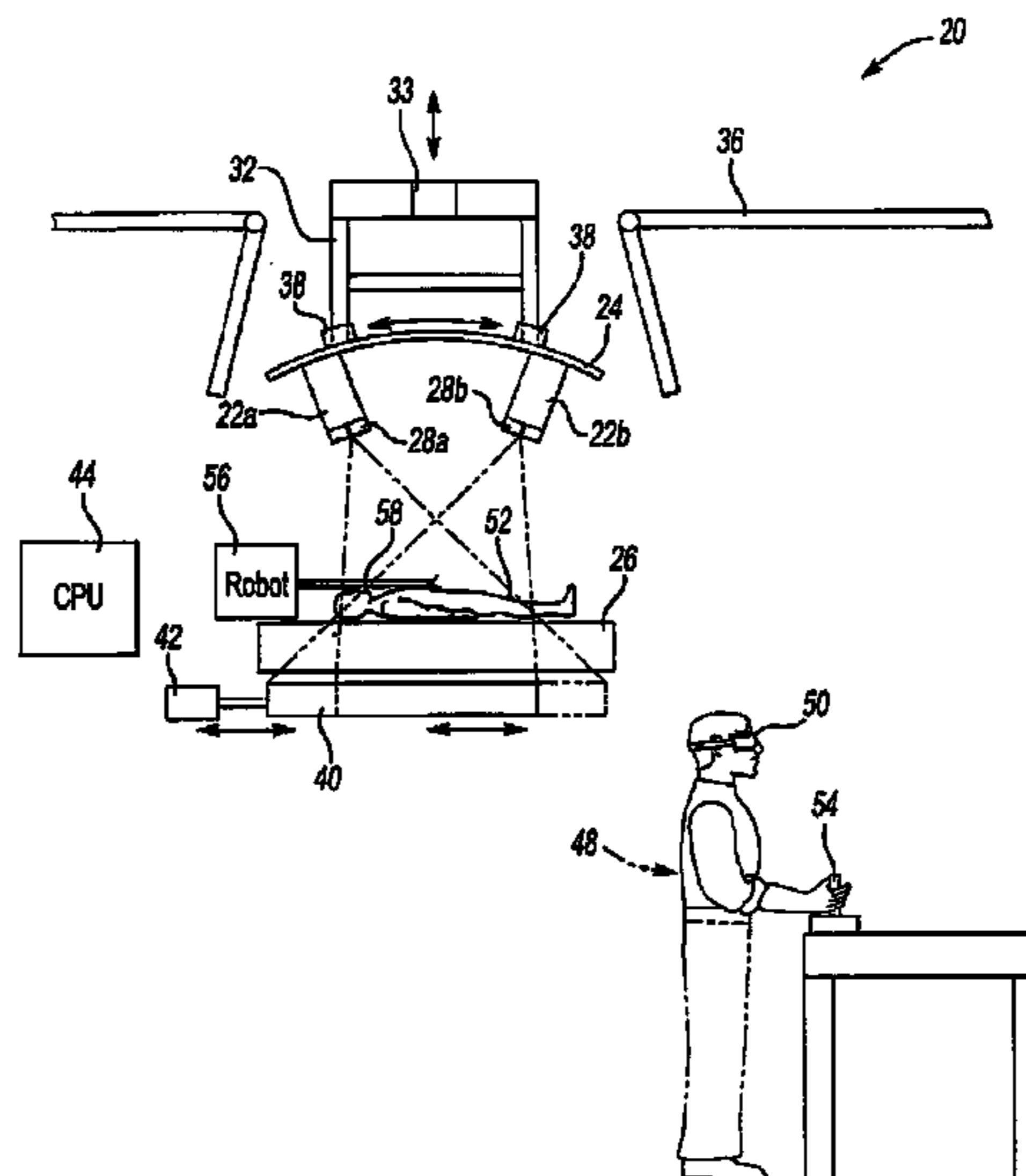
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(57) **ABSTRACT**

A surgical imaging system includes spaced-apart first and second x-ray sources mounted above a patient support surface. An x-ray detector mounted below the patient support surface generates first x-ray images based upon x-rays from the first x-ray source and second x-ray images based upon x-rays from the second x-ray source. These first and second x-ray images are used to generate a stereofluoroscopic image via a stereo display for a surgeon performing image-guided surgery. The stereofluoroscopic imaging system may be used in conjunction with robotic surgery. A surgical robot operatively controls a surgical tool in an area between the first x-ray source and the x-ray detector, and between the second x-ray source and the x-ray detector. The system may optionally include a first video camera mounted proximate the first x-ray source and a second video camera mounted proximate the second x-ray source. The stereo display selectively displays the first and second video images or the first and second x-ray image, and dissolves between the sources to correlate an outer view with the fluoroscopic view.

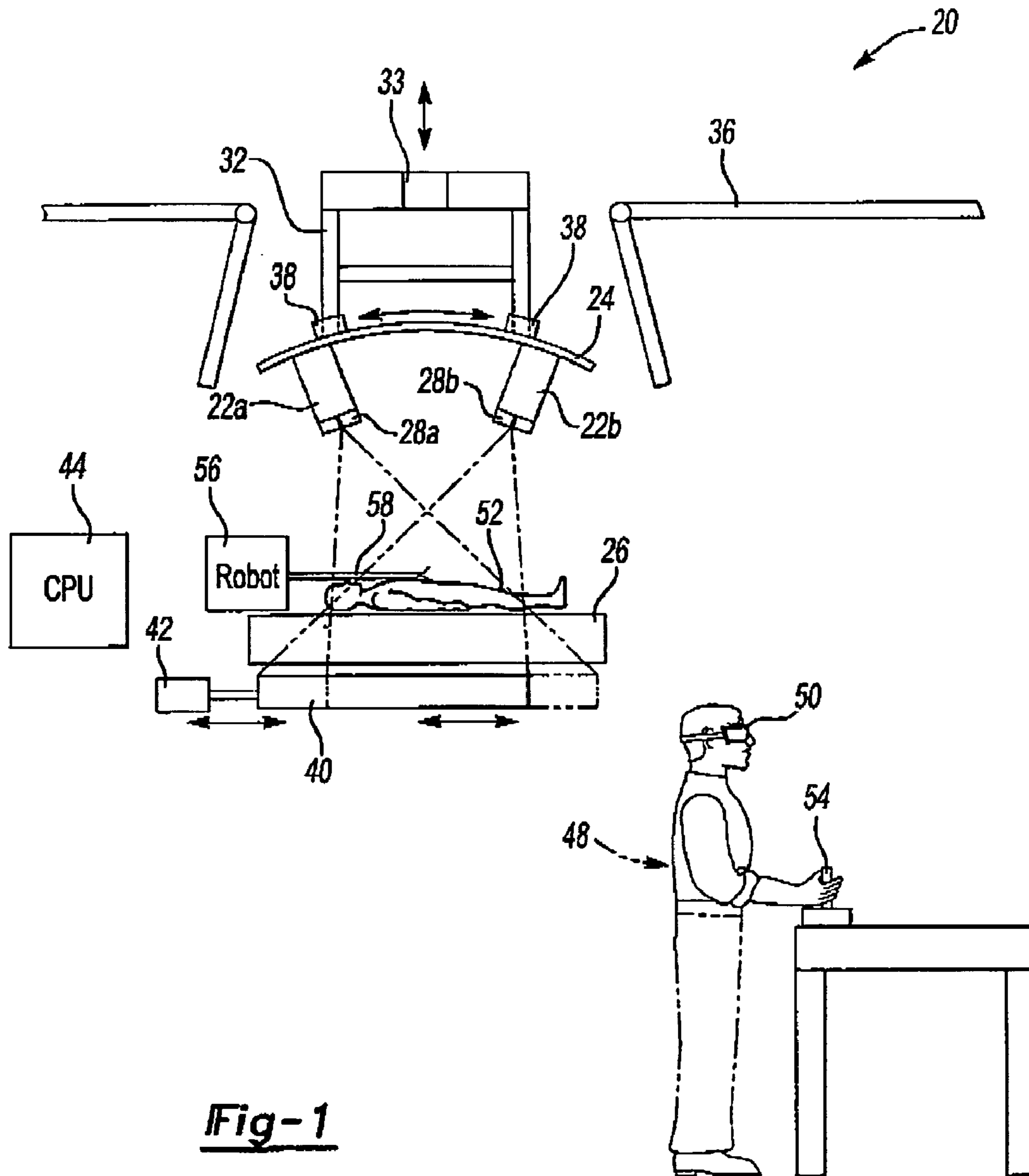
**13 Claims, 2 Drawing Sheets**

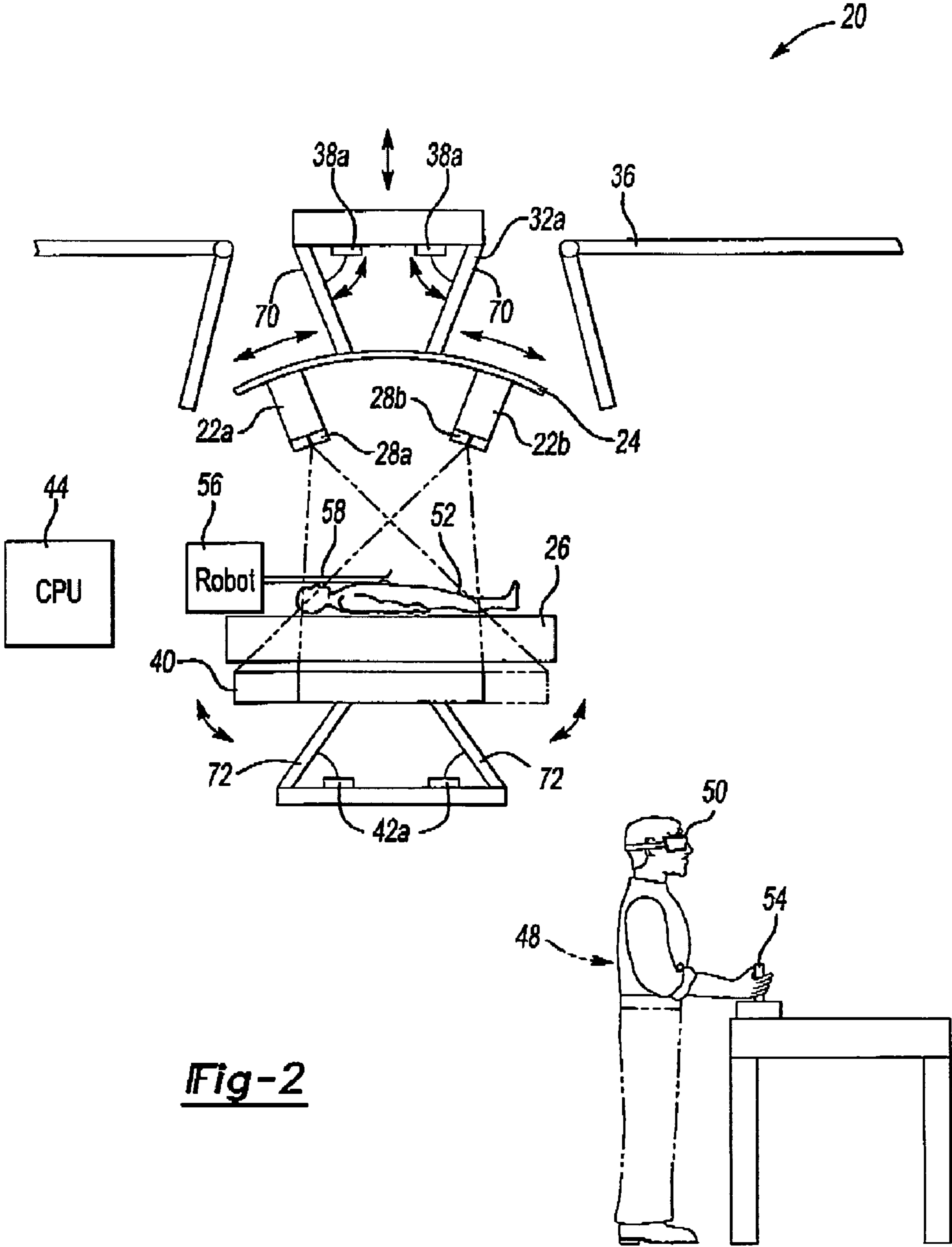


U.S. PATENT DOCUMENTS

5,799,055	A *	8/1998	Peshkin et al. ....	378/42	6,449,333	B1 *	9/2002	Yamasaki .....	378/42
5,944,663	A *	8/1999	Kuth et al. ....	600/411	6,490,475	B1 *	12/2002	Seeley et al. ....	600/426
5,951,475	A *	9/1999	Gueziec et al. ....	600/425	6,763,083	B2 *	7/2004	Fernandez .....	378/41
6,052,611	A *	4/2000	Yanof et al. ....	600/429	6,914,959	B2 *	7/2005	Bailey et al. ....	378/65
6,088,424	A *	7/2000	Postlethwaite et al. ....	378/63	7,008,373	B2 *	3/2006	Stoianovici et al. ....	600/101
6,256,372	B1 *	7/2001	Aufrichtig et al. ....	378/41	7,150,737	B2 *	12/2006	Purdy et al. ....	604/506
6,386,758	B2 *	5/2002	Loser .....	378/205	2001/0029334	A1	10/2001	Graumann et al.	
6,400,979	B1 *	6/2002	Stoianovici et al. ....	600/427					

\* cited by examiner





**Fig-2**

## INTRAOPERATIVE STEREO IMAGING SYSTEM

This application claims priority to U.S. Provisional Application Ser. No. 60/493,265 filed Aug. 7, 2003.

### BACKGROUND OF THE INVENTION

Image guided surgery is becoming more common. Systems are utilized to take data gathered from pre-operative scans by MRI, CT scanners, ultrasounds, or the like. The data is used to generate a three-dimensional image to guide a surgeon during an operation. Often this includes some method for tracking an instrument location with respect to the image displayed by the system. Generally, the image is registered relative to locators attached to the patient. Then, the position and orientation of the surgical instruments is registered and tracked relative to the image and the patient so that the location and orientation of the instruments relative to the image is continuously displayed while the surgeon performs the surgery. However, the current image-guided surgery relies on a preoperative scan. Changes to the surgical area during surgery are not reflected in the image by which the surgeon navigates.

Fluoroscopy is used in some types of surgery to provide a continuously updated image of the surgical area. However, the two dimensional nature of the fluoroscopy may not provide sufficient information for surgical navigation.

### SUMMARY OF THE INVENTION

A surgical imaging system according to one embodiment of the present invention includes spaced-apart first and second x-ray sources mounted above a patient support surface. An x-ray detector mounted below the patient support surface generates first x-ray images based upon x-rays from the first x-ray source and second x-ray images based upon x-rays from the second x-ray source. These first and second x-ray images are used to generate a stereofluoroscopic image via a stereo display for a surgeon performing image-guided surgery.

The stereofluoroscopic imaging system may be used in conjunction with robotic surgery. A surgical robot operatively controls a surgical tool in an area between the first x-ray source and the x-ray detector, and between the second x-ray source and the x-ray detector.

The system may optionally include a first video camera mounted proximate the first x-ray source and a second video camera mounted proximate the second x-ray source. The stereo display selectively displays the first and second video images or the first and second x-ray image, and dissolves between the sources to correlate an outer view with the fluoroscopic view.

### BRIEF DESCRIPTION OF THE DRAWINGS

Other advantages of the present invention can be understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 illustrates a first embodiment of a surgical navigation and imaging system according to the present invention.

FIG. 2 illustrates a second embodiment of a surgical navigation and imaging system according to the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention shown in FIG. 1 provides an imaging system 20 particularly useful for image-guided surgery, remotely-controlled robotic surgery or other applications where intra-operative imaging would be desired. Although potentially useful for other types of imaging systems, the present invention will be described with respect to an intra-operative CT scanning system 20.

Referring to FIG. 1, the imaging system 20 includes a pair of laterally offset sources 22a, 22b both mounted on a bracket 24 above a radiolucent operating table 26. The bracket 24 is mounted to a lift 32 that is powered by a motor 33 to extend and retract down from and into the ceiling 36 above the operating table 26. The bracket 24 is coupled to the lift 32 via motorized couplings 38 for selectively moving the bracket generally along an arcuate path. Alternatively, the bracket 24 may be mounted on a robotic arm.

The sources 22a, 22b may be cone-beam x-ray sources. Each of the sources 22a, 22b includes a video camera 28a, 28b, respectively. The video cameras 28a, 28b are positioned such that the field of view of the video image received by each video camera 28a, 28b substantially corresponds to the beam of x-rays emitted from the associated source 22a, 22b.

A detector 40 is mounted below the operating table 26 and is positioned to receive the x-ray beams from the sources 22a, 22b. As shown in FIG. 1, if the detector 40 is not large enough to receive the entire beam from both of the sources 22a, 22b the detector 40 may be translated back and forth (e.g., by a computer-controlled motor or actuator 42) between a first position for receiving an x-ray beam from the first source 22a and a second position for receiving an x-ray beam from the second source 22b.

The system 20 further includes a computer 44 that is suitably programmed to control the functions of all of the devices described herein and to perform the image-processing described herein.

A surgeon 48 views a display, such as a goggle stereo display 50, producing images from the detector 40 and sources 22a, 22b of the region of interest of the patient 52. An input device 54, such as a computer input device with haptic feedback, or other remote surgical device, controls a surgical robot 56. The surgical robot 56 uses surgical tools 58 to perform surgery on the patient 52 based upon the input from the surgeon 48 on the input device 54. Remote surgery, surgical robots and haptic feedback surgical devices are all described and known in the art.

In use, the sources 22a, 22b alternately generate x-rays that pass through the patient 52 and are received as images by the detector 40. These images from slightly different angles are displayed simultaneously to the surgeon 48 on the stereo display 50 and continuously updated to provide a three-dimensional image to the surgeon 48. Based upon the three-dimensional image, the surgeon 48 controls the surgical robot 56 in the surgery using the input device 54. The surgeon 48 can also remotely control movement of the bracket 24 and sources 22a, 22b to change the perspective of the three-dimensional view. Additionally, the surgeon 48 can choose for the stereo display 50 to toggle between or dissolve between an outer, visible three-dimensional view provided by the cameras 28a, 28b and the stereo fluoroscopy provided by the sources 22a, 22b and detector 40. In this manner, the surgeon 48 can remotely control the location and orientation of the sources 22a, 22b while watching the

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video images from the cameras **28a**, **28b** and then switch to the stereo fluoroscopy view when the desired portion of the patient is located.

Other variations of the present invention include the use of a single source that could be moved between the two locations to provide the stereo view. The surgical robot **56** could be used to move the source(s).

FIG. **2** illustrates a second embodiment of the imaging system **20** according to the present invention. If the sources **22a**, **22b** are rotated to change the viewing angle a sufficient degree, it may become necessary or desirable to rotate the detector **40** as well. In this embodiment, the bracket **24** holding the sources **22a**, **22b** and the detector **40** are mounted in four-bar linkages (shown only schematically in FIG. **2**, not to scale). The bracket **24** is mounted to two links **70** acted upon by computer-controlled motors or actuators **38a**. The detector **40** is similarly mounted to two links **72** controllably pivoted by computer-controlled motors or actuators **42a**. This provides an economical way to provide for controlled movement of the sources **22a**, **22b** and detector **40** about known arcs.

By providing for movement about known arcs about the patient **52**, the sources **22a**, **22b** and detector **40** can then additionally be used for computed tomography. If full angular range is provided (i.e. approximately 180 degrees), then a full CT scan can be performed by the system **20**. Alternatively, limited angle tomography can be performed intra-operatively based upon data from a complete pre-operative CT scan. The limited angle tomography can be used during surgery to update the data from a pre-operative full and complete CT scan. In that case, the computer **44** can generate a three-dimensional model of the current state of the patient **52** and can computer-generate a "simulated" three-dimensional angle to the surgeon's stereo display **50** based upon the updated three-dimensional model. The simulated three-dimensional model would be integrated with the image-guided surgical system, such that the position and orientation of the surgical robot tool **58** would also be displayed on the stereo display **50**.

In accordance with the provisions of the patent statutes and jurisprudence, exemplary configurations described above are considered to represent a preferred embodiment of the invention. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope. Alphanumeric identifiers in method steps are for the purpose of ease of reference in dependent claims and are not intended to signify a required sequence of performance, and unless otherwise explicitly stated, such sequence should not be inferred.

What is claimed is:

**1.** A surgical imaging system comprising:

a first x-ray source at a first location above a patient support surface;

a second x-ray source laterally spaced from the first x-ray source and above the patient support surface;

an x-ray detector mounted below the patient support surface, the x-ray detector generating first x-ray images based upon x-rays from the first x-ray source and second x-ray images based upon x-rays from the second x-ray source, wherein the x-ray detector is movable between a first position where the x-ray detector receives x-rays from the first x-ray source and a second position where the x-ray detector receives x-rays from the second x-ray source

an actuator for moving the x-ray detector relative to the first x-ray source and the second x-ray source from the

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first position to the second position and from the second position to the first position; and

a first video camera mounted proximate the first x-ray source and a second video camera mounted proximate the second x-ray source, the first video camera generating first video images, the second video camera generating second video images.

**2.** The system of claim **1** further including a surgical robot operatively controlling a surgical tool in an area between the first x-ray source and the x-ray detector, and between the second x-ray source and the x-ray detector.

**3.** The system of claim **2** wherein the first video camera has a field of view similar to that of the first x-ray source and the second video camera has a field of view similar to that of the second x-ray source.

**4.** The system of claim **3** further including a stereo display displaying the first and second x-ray images.

**5.** The system of claim **4** wherein the stereo display selectively displays the first and second video images or the first and second x-ray images.

**6.** The system of claim **1** further including a stereo display displaying the first and second x-ray images.

**7.** The system of claim **1** wherein the first x-ray source alternates generating x-rays with the second x-ray source.

**8.** The system of claim **1** wherein the actuator moves the x-ray detector in a first direction from the first position to the second position and in a second direction, opposite the first direction, from the second position to the first position.

**9.** The system of claim **8** wherein the actuator moves the x-ray detector substantially linearly.

**10.** A surgical imaging system comprising:

a first x-ray source at a first location above a patient support surface;

a second x-ray source laterally spaced from the first x-ray source and above the patient support surface;

an x-ray detector mounted below the patient support surface, the x-ray detector generating first x-ray images based upon x-rays from the first x-ray source and second x-ray images based upon x-rays from the second x-ray source, wherein the first x-ray source and the second x-ray source are mounted to move along an arc above the patient support surface; and

a surgical robot operatively controlling a surgical tool in an area between the first x-ray source and the x-ray detector, and between the second x-ray source and the x-ray detector, the x-ray detector generating the first x-ray images and the second x-ray images while the surgical tool is between the first x-ray source and the x-ray detector and between the second x-ray source and the x-ray detector, respectively.

**11.** The system of claim **10** wherein the first x-ray source and the second x-ray source are mounted to four-bar linkages.

**12.** The system of claim **10** wherein the detector is mounted to move along an arc.

**13.** A surgical imaging system comprising:

a first x-ray source at a first location above a patient support surface;

a second x-ray source laterally spaced from the first x-ray source and above the patient support surface;

an x-ray detector mounted below the patient support surface, the x-ray detector generating first x-ray images based upon x-rays from the first x-ray source and second x-ray images based upon x-rays from the second x-ray source;

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an actuator moving the x-ray detector between a first position where the x-ray detector receives x-rays from the first x-ray source and a second position where the x-ray detector receives x-rays from the second x-ray source; and  
a surgical robot operatively controlling a surgical tool in an area between the first x-ray source and the x-ray

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detector, and between the second x-ray source and the x-ray detector, the x-ray detector generating the first x-ray images and the second x-ray images while the surgical tool is between the first x-ray source and the x-ray detector and between the second x-ray source and the x-ray detector, respectively.

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